

UDC 666.293.04:666.119.232

SPECIFICS OF INTERACTION BETWEEN GLASS BATCH PARTICLES THROUGH TWO-COMPONENT SOLUTION INTERLAYERS

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Translated from Steklo i Keramika, No. 2, pp. 7–9, February, 2005.

The capillary force and crystallization strength of glass batch components are studied moistening the batch with solvents of sodium carbonate, sodium sulfate, and other components. The obtained data can be used for solving problems related to moistening glass batches.

Water drops in moistening a glass batch form liquid bridges linking the solid particles. The introduced water may partially dissolve crystals of soda and sodium sulfate, which affect the interaction of the components. We have earlier [1] published the first results of the analysis of the capillary-crystallization interaction of particles through interlayers of single-component aqueous solutions.

The present study considers the behavior of two solid particles linked by a capillary interlayer of two- and three-component solutions of sodium carbonate, sulfate, and hydroxide. We also studied the attraction of particles to distilled water cups. It was found that the main specifics of fixing particles with liquid bridges of aqueous solutions described earlier [1] remain; however, new regularities of the capillary-crystallization interaction of particles are revealed as well.

To study the adhesion forces we used a model of the spherical particle – liquid interlayer – flat substrate capillary contact. The strength of adhesion was measured in periodical removal of particles. Unlike the previous study [1], we modified the procedure of depositing a solution drop on a glass sphere. In this experiment the glass ball was immersed in an aqueous solution, whereas previously the drop was deposited on the ball with a glass rod. We additionally investigated sodium hydroxide solution and expanded the component concentration ranges.

Capillary-crystallization interaction through interlayers of two-component solutions of salts $\text{Na}_2\text{CO}_3 - \text{Na}_2\text{SO}_4$, $\text{NaOH} - \text{Na}_2\text{SO}_4$, $\text{NaOH} - \text{Na}_2\text{CO}_3$ and in the $\text{Na}_2\text{CO}_3 - \text{Na}_2\text{SO}_4 - \text{NaOH}$ system was investigated for concentrations of 0.25, 0.50, and 1.00 M. The compounds in the solutions were taken in equal ratio. One-component Na_2CO_3 and Na_2SO_4 solutions had been investigated earlier [1] and the specifics of interaction through caustic soda interlayers are shown in Fig. 1.

Sodium hydroxide solution can be used instead of water to moisten a glass batch. For concentrations of 0.25 and 0.50 M the regularities of the variation in the strength of contact through a sodium hydroxide interlayer are the same as for soda solution. Thus, with a concentration of 0.25 M the capillary force disappears in 6 min. On some curves after the end of the experiment the final force values are below the initial ones, apparently due to the transition to certain capillary microinterlayers. The capillary segment of the curve corresponds to strength varying from 0.75 to 1.20 mN. The regularity of capillary strength growing with decreasing volume of the water cup is observed. Sodium hydroxide has enhanced viscosity. This is presumably responsible for the fact that when the concentration grows to 1.0 M, it is impossible to determine precisely the moment of transition of the capillary force into a crystallization force based on the curves of dependence of capillary-crystallization strength on contact duration. The experiment duration with a sodium hydroxide concentration of 1.00 M is approximately 3 times longer than with other concentrations (0.25 and 0.50 M). The course of the curve $f=f(\tau)$ is also determined by the higher viscosity of the solution.

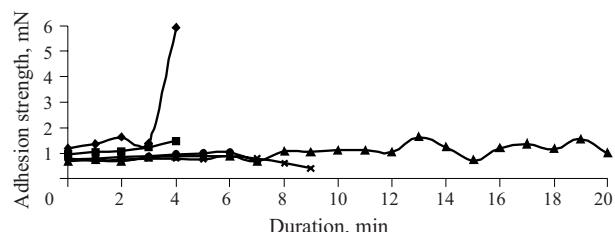


Fig. 1. Dependence of capillary-crystallization strength on contact duration: ◆) sodium sulfate, 0.50 M; ■) sodium carbonate, 0.50 M; ▲, × and ●) sodium hydroxide for concentrations of 1.00, 0.50, and 0.25 M, respectively.

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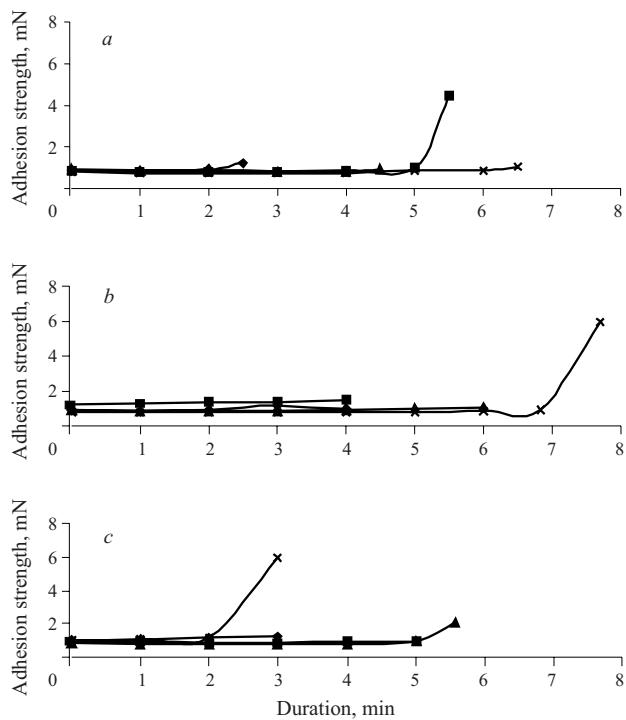


Fig. 2. Dependence of capillary-crystallization strength on contact duration (cup material — two-component solution $\text{Na}_2\text{SO}_4 - \text{Na}_2\text{CO}_3$, diameter of spherical particle 3.25 mm): *a*) solution concentration 0.25 M; ◆, ▲, ■, and ×) cup weight $m = 0.00055, 0.00165, 0.00150$, and 0.00240 g, respectively; *b*) solution concentration 0.50 M; ◆, ▲, ■, and ×) $m = 0.00205, 0.00295, 0.00240$, and 0.00330 g, respectively; *c*) solution concentration 1.00 M; ◆, ▲, ■, and ×) $m = 0.00185, 0.00120, 0.00240$, and 0.00125 g, respectively.

Two-component solution of sodium sulfate and sodium carbonate (Fig. 2) forms interlayers whose effect on particles is close to the earlier obtained dependences for single-component systems. The capillary and crystallization segments of experimental dependences are clearly defined. Thus, for a concentration of 0.25 M the maximum adhesion force is registered in the 6th min of the experiment (approximately 4.4 mN), for 0.50 M concentration approximately 6 mN in the 8th min, and in the solution with 1.00 M concentration the maximum adhesion strength of 6.2 mN is reached in the 3rd min. Consequently, with the concentration growing from 0.25 to 1.00 M the duration of the transition of capillary interaction to crystallization interaction decreases and the maximum adhesion force increases.

Solutions of the sodium hydroxide – sodium carbonate system exhibit some deviations from the typical course of the systems studied previously. Thus, in the solution with a concentration of 0.25 M (Fig. 3) the maximum crystallization strength is equal to 4 mN, whereas for higher concentrations there are no clearly defined segments of crystallization interaction.

With a concentration of 0.25 M the capillary and crystallization curve segments, the transition between which is observed in the 4th min, are clearly defined. The experiments

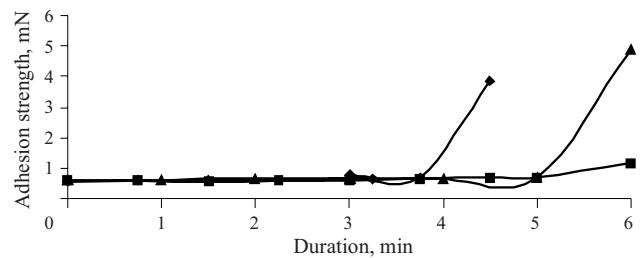


Fig. 3. Dependence of capillary-crystallization strength on contact duration (cup material $\text{NaOH} - \text{Na}_2\text{CO}_3$, $\text{NaOH} - \text{Na}_2\text{SO}_4$, $\text{Na}_2\text{SO}_4 - \text{NaOH} - \text{Na}_2\text{CO}_3$, concentration of solutions 0.25 M): ◆, ■ and ▲) $\text{NaOH} - \text{Na}_2\text{CO}_3$, $\text{NaOH} - \text{Na}_2\text{SO}_4$, and $\text{Na}_2\text{SO}_4 - \text{NaOH} - \text{Na}_2\text{CO}_3$, respectively.

with solution concentration of 0.50 and 1.00 M yield similar curves: there is no clearly defined segments of capillary and crystallization interaction. Crystallization interactions presumably coincide with capillary interaction in the first minutes of the experiment; accordingly, the curves run at a certain angle to the axis. Most probably, under high concentrations the binding properties of sodium hydroxide are manifested. The curves of the capillary-crystallization interaction for this compound have a “saw-like” shape and a longer duration (Fig. 1). The sodium hydroxide – sodium carbonate system typically has a rather low initial adhesion force compared to other materials, but it is higher than in the three-component system.

The sodium sulfate – sodium hydroxide system retains the main specifics of the capillary-crystallization interaction. However, similarly to the preceding system, there is a certain oscillation of the curves with respect to each other. Apparently, this is also due to the effect of sodium hydroxide on the course of the curves. With a concentration of 0.25 M the maximum adhesion force is registered in the 6th min of the experiment, i.e., about 1.2 mN, and with a concentration of 0.50 M the force of 4 mN is registered in the 4th min. For the low concentrations all curves have no clearly defined crystallization segment, which may be related to the small quantity of salt formed in the evaporation of the drop. With a concentration of 0.50 M the capillary and crystallization interaction is registered. This is probably due to the favorable conditions for the emergence of the crystalline contact. With a concentration of 1.00 M all dependences run parallel for 3 min and then a spread is observed: half of the curves have a small rise and some of them go downwards.

In the sodium-sulfate – sodium carbonate – sodium hydroxide system all components are present in a ratio of 1 : 1 : 1. For a concentration of 0.25 M the capillary segment is clearly defined: all curves start from the same point and run parallel. Then the capillary forces transform into crystallization strength in the 5th min of the experiment. The same properties are seen in the solution with 0.50 M: The duration of the experiment grows with increasing weight of the capillary liquid, although crystallization strength is different.

Analyzing the general course of the capillary-crystallization interaction of particles linked by an interlayer of aqueous salt solutions, one should note the following. Purely capillary interaction is registered for water, as was established earlier [1]. Due to evaporation, the volume of the liquid cup decreases with time. Consequently, the interaction force grows during the experiment, since the capillary force increases with decreasing volume of the liquid. In experiments with salt solutions the salt concentration with water evaporation gradually reaches its saturation level. Fine salt crystals start forming on the particle surface; therefore, there is no direct contact between the neighboring particles. A clearance emerges, whose size rapidly grows as the solution volume keeps decreasing. It is known that the capillary force decreases with increasing clearance. The coincidence of the two specified effects is responsible for the constancy of the interaction force in the initial segments of the curves $f_{cap} = f(\tau)$ (Fig. 1). The parallel course of the curve to the abscissa axis persists for some time.

For the selected measurement method the subsequent course of the curves to a great extent depends on the periodicity of measurements. If the measurements are performed as frequently as possible, a strong crystallization bridge between particles may not be identified. Otherwise, under protracted exposure of particles linked by a solution interlayer, a strong crystallization aggregate is always formed, where the force of interaction is determined by strong chemical bonds. There exists a certain lapse between measurements in which it is possible to register both capillary and crystallization components. In our case the period between the measurements was equal to 1 min. With this exposure cycle, crystals growing from the flat and the spherical glass particles start to penetrate into each other after 4 – 5 min. Some salts in cer-

tain cases manifest the setting of the crystalline phases at this site, whereas in other case there is no adhesion. To a certain extent the result of a contact between particles depends on random factors; however, even in this final stage it is sometimes possible to identify the effect of the type of the salt on fixing particles. This measurement method with a periodic supply of particles reflects the real behavior of a glass batch subjected to mechanical impacts.

Thus, the capillary force and the crystallization strength of interacting glass batch components in moistening are investigated. The capillary forces arise when the batch is moistened, which causes the consolidation and subsequent strengthening of the porous material. After the evaporation of water the strength of adhesion of particles depends on the crystallization contacts formed at the sites of water interlayers. This strength is several times higher than capillary strength. Crystallization bridges are formed and create a rigid skeleton, which prevents the segregation of the batch.

The use of a moistened batch allows for its preheating between melting, i.e., makes it possible to decrease the energy consumed in melting and the duration of the glass-melting process, to lower batch losses during its transportation and charging into the furnace, to decrease the volatilization of the batch components in melting, to improving glass quality, and to increase the furnace efficiency, which saves material, financial, and fuel resources.

REFERENCES

1. V. A. Deryabin, I. G. Voroshilova, and O. A. Shvartz, "Capillary-crystallization strength of glass batch components," *Steklo Keram.*, No. 9, 7 – 10 (2001).